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AUTHOR Tobin, Kenneth G.; Capie, William
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ABSTRACT

Students from thirteen middle school science classes participated in this study to determine their formal reasoning ability and locus of control. Students were observed through a sequence of lessons for their classroom behavior. Results indicated that achievement was related to high formal reasoning ability, attention to instruction, and internal locus of control, a result which reinforced the hypothesis that students who engaged in behaviors closely related to the instructional objectives achieve a higher level than those who do not. (JD)

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THE EFFECTS OF STUDENT ENGAGEMENT RATE, FORMAL REASONING ABILITY AND LOCUS OF CONTROL ON MIDDLE SCHOOL SCIENCE ACHIEVEMENT

Kenneth G. Tobin
William Capie

Department of Science Education
University of Georgia
Athens, Georgia

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INTRODUCTION

Science processes are intellectual skills used in collecting and analyzing data to solve problems. At the middle school level, five integrated process skills are often introduced and developed: defining operationally, interpreting data, formulating hypotheses, controlling variables and experimenting. Their introduction at this level rests on an assumption that basic process skills such as observing, classifying and measuring have been previously learned. Such skills are prerequisites for the development of integrated process skills.

Many educators have described the development of science process skills as a major objective of education (e.g., Okey, 1972: Jaus, 1975). Acceptance of this is evident in a growing emphasis on science processes in science programs developed in the past 20 years. It is somewhat surprising therefore, to find that little research has been directed toward identifying teacher and learner behaviors that are related to high science process achievement.

Doran and Sellers (1978) investigated the relationship between students' mental ability, gender, and biology achievement on science process achievement. The achievement measure contained items on experimenting, predicting, and concluding. From their analysis, the authors inferred that mental ability was a major component of process achievement. It should be noted, however, that biology achievement and mental ability together only accounted for nine percent of the variance in process skill achievement. Two studies were found in which

modes of formal reasoning were related to the use of science processes. Spears and Zollman (1977) reported that college students in an unstructured laboratory seldom followed the steps of observation, prediction; or hypothesizing. They attributed this to the inability of students at this level to apply formal-operational processes to physics. It should be noted that this was an inference as developmental levels of learners were not determined in this experiment. Lawson, Nordland and Devito (1975) reported a significant relationship between a measure of cognitive development and process skill acquisition.

Other literature has discussed the logical relationship between cognitive development and integrated science processes. Wood (1974) presented a Piaget-process matrix which focused on the need to consider the cognitive development of learners when planning a science program to teach process skills. The particular emphasis in the paper was on the obvious direct links between formal thought and integrated processes such as identifying and controlling variables and hypothesizing. Good (1977) raised doubts on the suitability of integrated process skills for students in grades 5 and 6. Good commented that: "...making generalizing hypotheses based on a logical analysis of data could not be expected of ten- and eleven-year-old children if cognitive development research and theory were to be taken seriously." Good also emphasized that identifying and controlling variables and interpreting data also require formal modes of thought. On the one hand, therefore, it would appear that cognitive limitations would prevent students from learning integrated process skills. On the other hand, it can be argued that exposure to a systematic science program which emphasizes integrated science processes can promote cognitive development.

PURPOSE

The purpose of this study was to investigate student variables that are likely to influence process skill learning. The research is based on the proposition that learner characteristics together with the quantity and type of academic engagement determine whether learning occurs.

Five research questions were formulated as a basis for the study. The model presented in Figure 1 depicts the hypothesized relationships.

1. How is variation in student engagement related to science process achievement?
2. How is variation in formal reasoning ability related to student engagement?
3. How is variation in formal reasoning ability related to science process achievement?
4. How is variation in student locus of control related to student engagement?
5. How is variation in student locus of control related to science process achievement?

(Include Figure 1 About Here)

RATIONALE

Stated simply, the rationale for this study is that pupil achievement depends on personological variables such as formal reasoning ability, locus of control and what pupils do in the classroom.

It is hypothesized that students who are engaged in behaviors that are closely related to the instructional objectives will achieve at a higher level than those who are not engaged in this way. Interest in academic time as an achievement related variable was stimulated by the learning model proposed by Carroll (1963). Since that time a growing number of studies have shown student achievement to be significantly related to academic engagement (e.g., Ladaherne, 1968; Cobb, 1972; Schultz, 1973; Samuels and Turnure, 1974; Hecht, 1978). In each of these studies

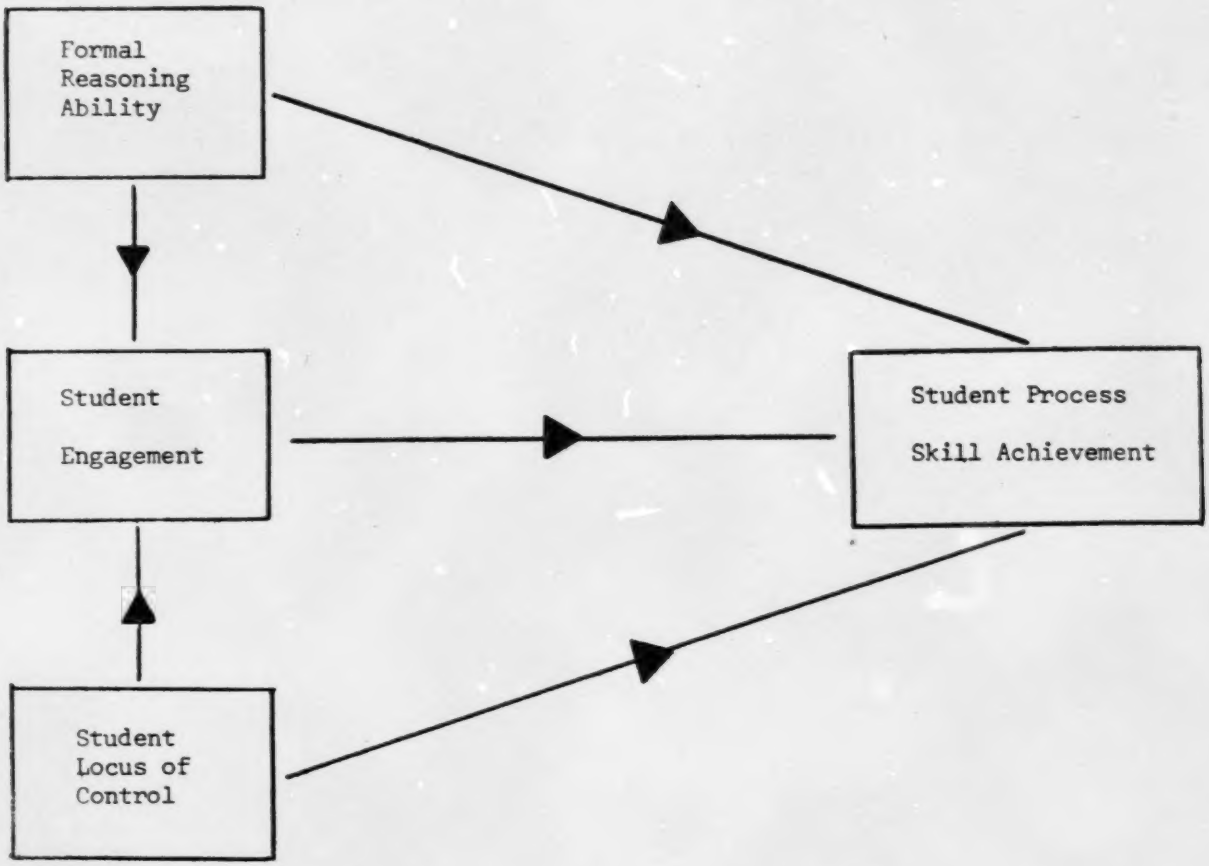

Figure 1. Hypothesized effects of learner characteristics and rate of engagement on process skill achievement.

engagement was conceptualized as a dichotomous variable and pupils were rated as engaged or not engaged. It is intuitively appealing that some categories of engagement are more closely related to achievement than others. Students who engage in categories related to process acquisition are expected to learn more than those who do not.

A set of pupil behaviors that were logically related to integrated science process learning was identified. Additional behaviors that frequently occurred in science were also identified and defined so that pupil behavior could be categorized without ambiguity. Eight categories of engagement were identified and operationally defined.

The activities that were used in this study required higher level abilities such as interpretation of data and formulation of hypotheses. It was anticipated that students with lower formal reasoning ability would find such objectives difficult to achieve. This could result in a lack of success which could lead to a higher incidence of off-task behavior among students with lower formal reasoning ability.

A number of researchers have reported a significant relationship between level of cognitive development and science achievement (e.g., Cantu and Herron, 1978). Others such as Good (1977) have postulated that formal operations are required for students to learn to use integrated science processes. Because of the close relationship that exists between formal modes of reasoning and the use of integrated processes, it was expected that students with higher levels of formal reasoning would achieve at a higher level than students with lower levels of cognitive development.

Since students with an internal locus of control tend to accept responsibility for academic achievement, it was expected that such students would exhibit a higher frequency of academic engagement. Research

has also indicated (e g., Davis and Phares, 1967) that students with an internal locus of control are more likely to engage in data gathering activities and make greater use of information than students with an external locus of control. Other studies (e.g., McGhee and Crandall, 1968) reported that internals attained higher course grades and achievement test scores than students with an external locus of control.

PROCEDURES

Thirteen intact classes from four middle schools in Clarke County, Georgia were selected to participate in the study. Five of the selected classes were from grade 8, four from grade 7 and four from grade 6.

The students participating in the study were heterogeneous with respect to socio-economic status, race and intelligence. The range on each of these variables within each class was similar for all participant classes in accordance with a policy of heterogeneous grouping that is adopted in the school district.

The design for the study can be represented in the following way:

$$O_1\ O_2\ X_1\ O_3\ X_2\ O_4$$

O_1: locus of control measure

O_2: formal reasoning measure

O_3: summative measure of science process skills

O_4: retention measure of science process skills

X_1: process skill lessons

X_2: content oriented lessons

A sequence of eight science lessons was presented in each class over a two week period of time. Each lesson was developed from a learning hierarchy to promote the acquisition of twelve objectives related to hypothesizing interpreting data, identifying and controlling variables and defining operationally. The instructional objectives are presented

in Figure 2. For a period of four weeks following the summative measure, all classes were involved in lessons that emphasized science content rather than the science processes. The retention measure was administered after this time.

(Include Figure 2 About Here)

Selection of Subjects

All students participating in the study were tested on the four measures shown in the design. A quasi-random sampling procedure was used to select twelve students from each class as data sources for categories of academic engagement. Prior research (e.g., Tobin and Capie, 1980), suggested that only a small percentage of students would obtain high formal reasoning scores. To satisfactorily investigate the research questions however, it was essential that a broad range of formal reasoning ability was represented in the sample to be observed. Within each class, four students were randomly selected from those scoring greater than three on the Test of Logical Thinking, four students from those scoring two or three, and four students from those scoring less than two. The procedure was modified for classes where less than four students were represented in the highest category.

Since formal reasoning ability and locus of control are uncorrelated (Tobin and Capie, 1979), it was anticipated that this sampling procedure would also ensure a suitable range on the locus of control measure.

Academic Engagement

Transactions in Science (TIS) defined eight categories of student engagement and one off-task category (see Figure 3). Two procedures were used to identify the categories to be included on TIS. In the first

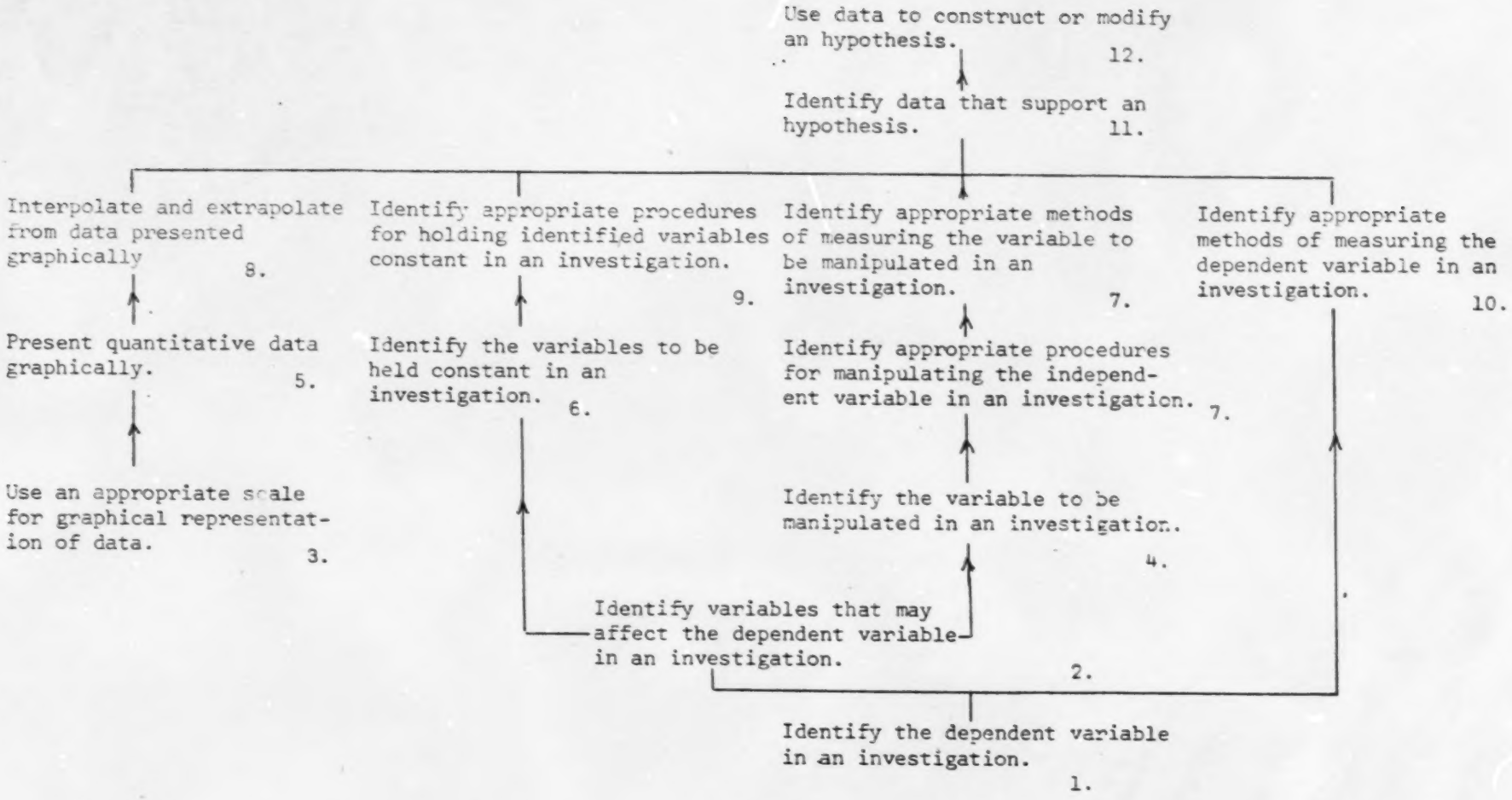
Use data to construct or modify an hypothesis. 12.
Identify data that support an hypothesis. 11.
Interpolate and extrapolate from data presented graphically 8.
Identify appropriate procedures for holding identified variables constant in an investigation. 9.
Identify appropriate methods of measuring the variable to be manipulated in an investigation. 7.
Identify appropriate methods of measuring the dependent variable in an investigation. 10.
Present quantitative data graphically. 5.
Identify the variables to be held constant in an investigation. 6.
Identify appropriate procedures for manipulating the independent variable in an investigation. 7.
Use an appropriate scale for graphical representation of data. 3.
Identify the variable to be manipulated in an investigation. 4.
Identify variables that may affect the dependent variable in an investigation. 2.
Identify the dependent variable in an investigation. 1.

Figure 2. A hierarchy for planning and conducting an investigation.

Category	Definition
1. Attending	Looking at the teacher, book, worksheet, paper, chalkboard, etc. Physically attending to a task.
2. Recalling	Responding to questions with recalled facts. Stating definitions. Stating names and/or terms without explaining their meaning. Stating matters of fact.
3. Collecting	Collecting data in an investigation. Copying material from books or the chalkboard, etc. Recording data in an investigation.
4. Comprehending	Explaining the meaning of a term. Naming data points on a graph. Describing graphic or tabular data. Reporting techniques. Reporting data. Representing data in a different mode.
5. Quantifying	Calculating relations between data. Reducing many bits of data to a representative value. Determining a scale for graphic representation of data. Reducing many bits of data to sub-groups. Classifying data into sub-groups.
6. Planning	Identifying variables that are relevant to a given problem. Identifying the dependent variable in an investigation. Identifying the variables that may affect the dependent variable in an investigation. Identifying the independent variable to be manipulated in an investigation. Identifying procedures for manipulating the independent variable in an investigation. Identifying the variables to be controlled in an investigation. Identifying procedures for controlling variables in an investigation. Identifying methods of measuring the dependent variable in an investigation. Identifying variables to label the axes of a graph or to be the headings on a table.

Figure 3. Defining categories of Transactions in Science.

Category	Definition
7. Generalizing	Comparing data from an investigation. Identifying data that support an hypothesis. Interpolating between or extrapolating beyond data points in tables or graphs. Using data to construct an inference. Using data to construct an hypothesis. Justifying an explanation or a decision.
8. Non-Cognitive	Non-cognitive behaviors that are goal-directed. e.g., collecting items of equipment. Assembling apparatus.
9. Off-Task	Behaviors that are not goal-directed. e.g., reading a book while the teacher is explaining how to solve a problem.

Figure 3. Defining categories of Transactions in Science. (Continued)

instance, categories of engagement that were logically related to the acquisition of integrated science processes were included (e.g., planning, generalizing, comprehending). The second procedure was to include behaviors that frequently occurred in science classes (e.g., attending, recalling) so that the universe of behaviors were encapsulated by the instrument.

(Include Figure 3 About Here)

In this study the behavior of each student was observed for one lesson of every two using a time sampling procedure in which behavior was observed for four seconds during each 30 second interval. If more than one codable behavior occurred in the four second interval, the predominant behavior to occur in that interval was recorded. The order in which students were observed was randomly determined.

Frequency counts constituted the raw data for the analysis. For each student, behavior over the four lessons that were rated was pooled to enable proportions to be calculated for each category of engagement. These indices represent the proportion of time each student allocated to each category of engagement.

The proportion of time allocated to each mode of engagement was used as the unit for analysis for hypotheses related to student engagement. Because the use of arc sine transformations is often advocated for proportional data (Myers, 1979), all analyses were conducted twice, with and without the transformation. The results obtained were substantively the same. In view of the caution expressed by Keppel (1973) the results reported are not based on the transformed data.

A generalizability coefficient of .91 was obtained as an estimate of the dependability of the data for differentiating students and categories of engagement in all lessons.

Formal Reasoning Ability

Formal reasoning ability of students was measured with a multiple response, paper and pencil test developed by Tobin and Capie (1980). The Test of Logical Thinking (TOLT) consists of ten items which provide a measure of formal reasoning on five dimensions: proportional reasoning, controlling variables, combinatorial reasoning, probabilistic reasoning and correlational reasoning. Two items for each mode of thinking are contained in the test.

TOLT has high internal consistency (α = .85) and evidence supports construct, predictive and criterion-related validity (Tobin and Capie, 1980).

Locus of Control

The Intellectual Achievement Responsibility (IAR) scale (Crandall, Katkovsky and Crandall, 1965) was used to obtain a measure of locus of control. The internal consistency reliability (Cronbach's α) of the locus of control scale was .66.

Integrated Science Processes

Integrated science process achievement was measured on two occasions with a 24 item, criterion-referenced test. The pencil and paper, multiple response test, consisted of two items for each of the twelve instructional objectives contained in Figure 2.

(Include Figure 2 About Here)

The content validity of the test was established by a panel of three judges who assessed the match between the test items and instructional objectives. The test reliability for the research hypotheses in this study was .81.

RESULTS

The results of the analyses of the research questions are presented in the four sections that follow.

The Effects of Variation in Engagement on Achievement

The rates of academic engagement are presented in Table 1. With the exception of attending (33 percent) and collecting (15 percent) the engagement rates for each category were low. The correlation matrix in Table 2 shows that collecting, comprehending, quantifying, planning, and non-cognitive were all positively correlated with achievement. In each case however, the magnitude of the correlation was small and statistically non-significant.

The highest correlates of summative achievement and retention were attending ($r = .31$, $p < .0001$) and generalizing ($r = .36$, $p < .0001$). Students who attended to instruction tended to achieve at a higher level than those who did not. Similarly, those students who exhibited higher rates of generalizing behavior also tended to attain higher achievement scores.

On the basis of the relative magnitude of the correlations of engagement categories with other student variables, subsequent analyses involving student engagement were confined to attending and generalizing.

(Include Table 1 &
Table 2 About Here)

TABLE 1

Rates of Academic Engagement

Category	Mean	Standard Deviation
Attending	33.12	14.97
Recalling	5.39	5.46
Collecting	14.63	8.83
Comprehending	4.54	3.79
Quantifying	0.51	0.90
Planning	0.38	0.72
Generalizing	1.10	1.51
Non-cognitive	2.92	3.65
Total	62.59	

TABLE 2

The Relationships between Categories of Student Engagement with Process Learning, Locus of Control and Formal Reasoning Ability

Category	Locus of Control	Formal Reasoning	Summative	Retention
Attending	.21***	.14	.31*	.26**
Recalling	.12	-.05	-.02	-.02
Collecting	.05	-.05	.10	.04
Comprehending	.06	.19	.13	.11
Quantifying	-.04	.06	.12	.04
Planning	-.002	.08	.13	.08
Generalizing	-.03	.23***	.36*	.37*
Non-cognitive	.03	.16	.12	.14

* $p < .0001$
** $p < .001$
*** $p < .01$

The Effects of Formal Reasoning and Locus of Control on Engagement

The results of the analysis of the relationship of locus of control and formal reasoning with generalizing and attending are contained in Table 3. A significant interaction was obtained in the analysis with generalizing as the dependent variable. Students with higher levels of locus of control and formal reasoning ability tended to exhibit higher frequencies of generalizing behavior. Although the variance attributable to the model is statistically significant in the analysis (Table 4), the results have little practical importance since only seven percent of the variance in generalizing can be attributed to the model.

(Include Table 3 About Here)

The analysis with attending as the dependent variable indicates that locus of control is closely related to attending ($F = 8.99$, $p = .003$). Although formal reasoning ($F = 3.64$, $p = .06$) and the L x F interaction ($F = 2.86$, $p = .09$) are not significant at the 5 percent level, it is possible that the analysis lacks statistical power due to the comparatively low reliability of the IAR scale.

The Effects of Formal Reasoning and Locus of Control on Achievement

The correlations between formal reasoning ability and process achievement were on the order of .6 for summative achievement and retention. In contrast, the locus of control was not correlated with achievement on either occasion, the correlations obtained being close to zero.

Multiple regression analyses with formal reasoning ability and locus of control as independent measures were conducted for summative and retention outcomes respectively. The results of these analyses are contained in Table 4.

(Include Table 4 About Here)

TABLE 3

Multiple Regression Analysis of Attending and Generalizing on Formal Reasoning Ability and Locus of Control

Dependent Variable: Generalizing

Source	ss	df	F	p
Locus of control (L)	2.96	1	1.39	.24
Formal reasoning (F)	11.97	1	5.63	.02
L x F	8.39	1	3.95	.05
Error	304.07	143		

R-Square: .07

Dependent Variable: Attending

Source	ss	df	F	p
Locus of control (L)	1947.21	1	8.99	.003
Formal reasoning (F)	787.79	1	3.64	.06
L x F	620.37	1	2.86	.09
Error	30975.00	143		

R-Square: .08

TABLE 4

Multiple Regression Analysis of Summative Achievement and Retention on Formal Reasoning Ability and Locus of Control of Learners

Dependent Variable: Summative Achievement

Source	ss	df	F	p
Formal reasoning	1575.96	1	117.67	.0001
Locus of control	2.23	1	.17	.68
Error	3656.17	273		

R-Square: .30

Dependent Variable: Retention

Source	ss	df	F	p
Formal reasoning	1642.02	1	103.12	.0001
Locus of control	10.46	1	.66	.42
Error	3965.11	249		

R-Square: .30

Locus of control and formal reasoning ability were found to account for 30 percent of the variance in the summative measure. Only formal reasoning ability accounted for a significant proportion of the variance. A similar result was obtained for the retention measure. Formal reasoning was again found to be significantly related to retention. The interaction between formal reasoning ability and locus of control was non-significant in each analysis.

Combined Effects of Engagement, Formal Reasoning and Locus of Control on Achievement

The effects of academic engagement on achievement were considered concomitantly with formal reasoning and locus of control. A regression procedure was used to determine the collective effects of attending, generalizing, locus of control and formal reasoning on science process achievement. Similar results were obtained for the summative and retention measures. From the data presented in Table 5 it can be seen that formal reasoning ability, attending and generalizing accounted for 35 percent of the variance in the summative measure and 45 percent of the variance in retention. In both analyses, each variable contributed a significant proportion of the additional variance in the presence of the other variables. Locus of control was not significantly related to achievement or retention in the presence of the other student variables.

(Include Table 5 About Here)

DISCUSSION

It was somewhat surprising to find that the proportion of time students were overtly engaged in objectives-related behaviors was small. Although the majority of the objectives were related to planning and generalizing, the average rate of student engagement on these categories

TABLE 5

Multiple Regression Analysis of Science Process Achievement on Formal Reasoning Ability, Attending and Generalizing

Dependent Variable: Summative Achievement

Source	ss	df	F	p
Formal reasoning	567.87	1	41.95	.0001
Attending	109.19	1	8.07	.005
Generalizing	78.67	1	5.87	.02
Error	1922.08	142		

R-Square: .35

Dependent Variable: Retention

Source	ss	df	F	p
Formal reasoning	978.00	1	69.97	.0001
Attending	59.77	1	4.24	.04
Generalizing	118.62	1	8.86	.004
Error	1859.07	132		

R-Square: .45

was .4 percent and one percent respectively. It is evident that the predominant means of engaging in objectives-related behavior was by attending to the teacher. The data in Table 1 indicate many potential areas for increasing the rate of student engagement. For example, rates of planning and generalizing behaviors might be increased by reducing the amount of off-task behavior.

Although attending and generalizing were the only behaviors significantly related to achievement, it is probable that others, such as planning, are also of importance. A possible explanation for low correlations in such instances is that a low frequency of occurrence truncated the true correlations.

Formal reasoning was the strongest predictor of process skill outcomes. This finding underscores the importance of formal reasoning to achievement in science. Teachers should be aware that the majority of middle school students will have difficulty in learning to use the integrated process skills. The teaching strategies should be designed and selected to facilitate the development of reasoning skills that are still at a formative stage.

Attending and generalizing together with formal reasoning were related to both achievement and retention. While formal reasoning was the most important factor, there is the possibility of increasing achievement by influencing the other two variables. Teachers could attempt to increase the attending behavior of students and provide more time for generalizing, as well. This area must be interpreted cautiously since several alternative explanations are equally plausible. It may have been that only students with high levels of formal reasoning could formulate responses that were applicable to the generalizing category. It is also possible that teachers called only on those students who were

capable of providing the desired interpretation or justification. Although it is not possible to conclude that the use of generalizing behavior will lead to achievement, it does seem reasonable for teachers to induce students to do more generalizing in science classrooms.

The attending behavior was interesting in that it was also related to locus of control. It is possible that knowledge of locus of control could help a teacher maintain better involvement among external students. In a long term sense, strategies might be devised to assist students in becoming more internal. This is clearly an area for additional research. A potential problem in this study has been the comparatively low reliability of the IAR scale. Replications using a revised instrument with higher reliability would increase the chances of finding hypothesized relationships when they actually exist.

Further research is needed on the relative importance of types of engagement on science process achievement. To assure sufficient variability on each engagement category, researchers should endeavour to manipulate student behavior. This might be achieved by providing teachers in different treatment groups with lesson plans which emphasize different behaviors and/or providing feedback on behavior of specific students. Effects on achievement can be more accurately determined if a suitable range is obtained on each category.

CONCLUSION

Integrated science process achievement is closely related to formal reasoning ability. The results of this study indicate that students may be limited in their ability to learn integrated process skills by low formal reasoning ability. Achievement was also related to two categories of student engagement: attending to instruction, and generalizing. It is possible that student achievement could be improved by increasing the proportion of time allocated to these categories of engagement.

The effects of student locus of control were also investigated in this study. Locus of control was not directly related to achievement but was significantly related to the amount of attending behavior of students.

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